16-March-2001

Beam loss in the SNS linac

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INTRODUCTION

This note serves to define beam losses as sources for activation calculations in the SNS linac under normal operating conditions. Estimates for a maximum credible accident will be made at a later stage. Primary beam loss mechanisms considered here include gas stripping, and scraping due to halo and beam excursions caused by errors in linac sub-systems (e.g. steering, RF etc.). Magnetic stripping, nuclear scattering and Coulomb scattering effects have been calculated [1] to be unimportant contributors to loss for the SNS linac.

BEAM LOSS DUE TO RESIDUAL GAS IN THE VACUUM

In order to calculate this loss, one can assume an average beam current of 2 mA and a vacuum in the MEBT of $5x10^{-7}$ Torr, in the DTL of $9x10^{-8}$ Torr, in the CCL of $5x10^{-8}$ Torr, in the SCL warm sections of $1x10^{-9}$ Torr and $5x10^{-8}$ Torr in the following 9 periods after the last cryomodule. The constituency of the residual gas in the DTL and CCL has been assumed to be the following RGA measured one from LEDA :

H_2	18%	CH_4	3%	H_2O	20%
N_2	49%	CO_2	7%	CO	3%

The residual gas in the SCL warm sections has been taken to be 100% H_2 .With the method outlined in [2], with cross sections from [3],[4], the loss rates from (single) H^- stripping are found to be as shown in Table 1. The majority of the stripped H^- goes to the neutral state. For the start of the DTL tank1, such a neutral would typically be lost 1.25 cm/12 mrad or ~ 1 m downstream from the point of formation (see table 1).
For a residual gas pressure of 10^{-7} Torr, large charge-changing cross sections for double stripping of H^- to p^+ have been calculated for the first 30 to 50 cm of the RFQ [5],[6]. About 50 nA of protons are thus created in the RFQ and accelerated to 86 Mev (i.e. the output of the DTL) which would be finally lost in the first module of the CCL, where the RF frequency changes from 402.5 to 805 MHz.

BEAM LOSS DUE TO HALO

To estimate the likely locations of beam halo loss, we first look at the beam envelope relative to the aperture. Fig.2 and 3 show results from beam envelope calculations for the DTL and CCL done with TRACE3D using a matched 0.2 π mm.mrad matched beam. From it one can conclude that the DTL tank 1 and the high-energy end (>145 MeV) of the CCL have an aperture to beam size of 1 for a 6σ beam. This ratio is about 2 for the SCL (April 2000 design) if one projects the half aperture of the warm sections all along the SCL.

POSITION	***ENERGY RANGE (MeV)***	***LENGTH (m)***	***STRIPPING LOSS RATE (nA/m)***	***HALO LOSS RATE (nA/m)***	***DOUBLE STRIPPING LOSS RATE** (nA/m)***	***TOTAL LOSS RATE (nA/m)***	***Av.Tot. LOSS RATE (W/m)***	***AVERAGE RMS BEAM DIVERGENCE (mrad)***	***HALF APERTURE (cm)***
MEBT	2.5	3.6	623	***	0	623***	1.56		
DTL tank 1	2.5- 7.5	4.2	112	32	0	144	0.72	12	1.25
DTL tank 2	7.5- 22.3	6.1	40	8	0	48	0.72	4.5	1.25
DTL tank 3	22.3- 39.8	6.3	14	1	0	15	0.47	1.6	1.25
DTL tank 4	39.8- 56.6	6.4	8	1	0	9	0.44	1.6	1.25
DTL tank 5	56.6- 72.5	6.3	6	1	0	7	0.45	1.6	1.25
DTL tank 6	72.5- 86.8	6.3	4.5	1	0	5.5	0.44	1.6	1.25
CCL module 1	86.8-107.2	11.8	2.3	8	3.3	13.6	1.32	1.6	1.50
CCL module 2	107.2-131.1	13	1.9	1	0	2.9	0.35	1.4	1.50
CCL module 3	131.1-157.2	14	1.5	1	0	2.5	0.36	0.9	1.50
CCL module 4	157.2-185.6	15	1.2	2	0	3.2	0.55	0.9	1.50
SCL low beta*	185.6-379	18	<0.005	<0.2	0	<0.2	<0.06	0.6	3.65
SCL high beta*	379 -1000	19	<0.003	<0.2	0	<0.2	<0.14	0.2	3.65
Suppl. 9 modules	1000	71	<0.150	<0.2	0	<0.35	<0.35	0.2	3.65

Table 1 Estimation for beam losses due to beam halo and stripping.

* For the SCL, loss rates and length are for the warm sections (for 11 low and 12 high beta periods). Losses in the cold sections should be smaller still.

** Double stripping losses correspond to protons created in the RFQ, which we assume to be lost in the first module of the CCL.

*** Loss in the MEBT is mainly governed by the chopper, giving a controlled loss of 4.2%

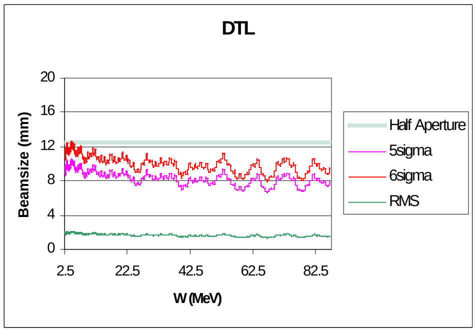

Figure 2 Beam sizes for the DTL

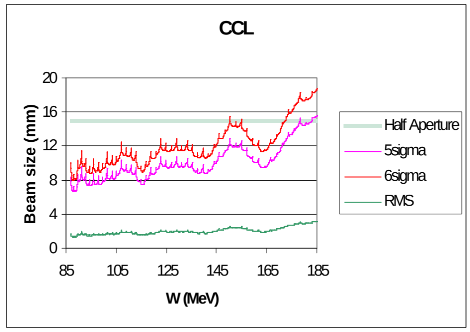

Figure 3 Beam sizes for the CCL

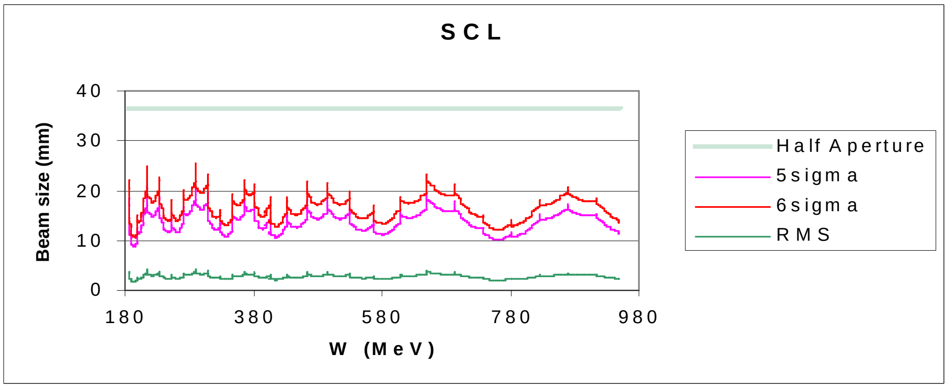

Figure 4 Beam sizes for the SCL (April 2000 design).

Simulations, which transport a beam, comprised of 10E6 macro-particles in a semi-realistic distribution, through an error-free linac indicate no anticipated beam loss in the DTL [7]. We are well aware of the limitations of such simulations and therefore make use of statistical analysis and operational experience to estimate expected beam losses. Using idealized beams and random sets of construction, tuning and operational errors, we simulate multiple linacs (~1000) to estimate the probability of beam loss. With one exception, the error tolerances have been specified to avoid any beam loss with about a 90% confidence level. An unfortunate set of alignment errors could result in calculable losses even though individual errors are within tolerance (see Fig. 5 and 6).

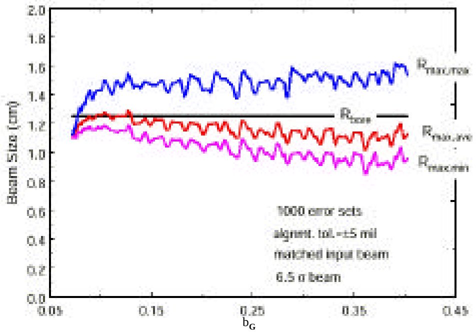

Fig.5 Maximum beam excursions are a function of drift tube alignment

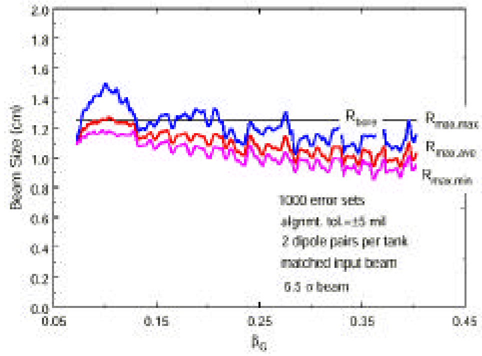

Fig.6 Beam steering uses 4 dipoles & 2 BPMs in each tank

Separately, we attempt to discover effects which cause halo to develop on the beam. The dominant source of halo is beam mismatch which results from certain design constraints and poor tuning. Assuming that present dynamic tolerances on rf phase and amplitude are not exceeded, we expect minimal loss due to longitudinal "spill".

Simulations to date indicate that a realistic, well matched, well behaved beam will develop a transverse halo extending to 6.5 sigma radially at a nA level. In reality this will almost certainly be worse. Assuming a given beam size we can calculate the beam-bore filling-factor with and without misalignments.

The filling factor tells us how close the edge of the beam will approach the bore. A small filling factor tells where we might expect beam losses to occur. We do not try to estimate the magnitude of losses from simulations but rather rely on operating experience for such estimates (see [8]).

Taking LANSCE as a basis for loss terms, LANSCE experience shows a beam loss of approximately 8 nA/m in the DTL-CCL transition region (at about 100 MeV) and 2 nA/m in the CCL at 200 MeV, in a region where the transverse focusing changes [8].

Comparing now to the SNS linac and taking into account the better aperture to beam size ratio for this linac (about a factor 2) as well as the higher average current (2 mA in stead of 1 mA), we can estimate the beam losses for the CCL and the SCL to be similar to those at LANSCE. Loss for the DTL has been estimated through scaling the above losses with energy.

REFERENCES

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[5] R.Shafer, "Proton Acceleration and Loss in the SNS H^- Linac", LANL, 10/27/2000
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